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Cross-modal tactile-taste interactions in food evaluations

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Abstract

Detecting the taste components within a flavoured substance relies on exposing chemoreceptors within the mouth to the chemical components of ingested food. In our paper, we show that the evaluation of taste components can also be influenced by the tactile quality of the food. We first discuss how multisensory factors might influence taste, flavour and smell for both typical and atypical (synaesthetic) populations and we then present two empirical studies showing tactile-taste interactions in the general population. We asked a group of average adults to evaluate the taste components of flavoured food substances, whilst we presented simultaneous cross-sensory visuo-tactile cues within the eating environment. Specifically, we presented foodstuffs between subjects that were otherwise identical but had a rough versus smooth surface, or were served on a rough versus smooth serving-plate. We found no effect of the serving-plate, but we found the rough/smoothness of the foodstuff itself significantly influenced perception: food was rated as significantly more sour if it had a rough (vs. smooth) surface. In modifying taste perception via ostensibly unrelated dimensions, we demonstrate that the detection of tastes within flavours may be influenced by higher level cross-sensory cues. Finally, we suggest that the direction of our cross-sensory associations may speak to the types of hedonic mapping found both in normal multisensory integration, and in the unusual condition of synaesthesia.

Introduction

The chemical sense of gustation (taste) involves the detection of five basic taste categories of sweet, sour, bitter, salty and umami or savoury (e.g. see Chaudhari & Roper, 2010). Tastant molecules bind (either directly or indirectly) to ion channels in the membranes of taste receptor cells in the mouth, which are organised into taste buds (Chandrashekar, Hoon, Ryba & Zuker, 2006). From there, the signal is converted and sent to the brain in a process known as transduction (e.g. see Frank & Hettinger, 1992). However, substances are very rarely delivered into the mouth in the form of pure tastes. Most consumption is of foodstuffs that have complex flavours involving not only taste but also texture (Philipsen, 1995), temperature (Talavera, Ninomiya, Winkel, Voets & Nilius, 2007), other tactile sensations (Cardello, 1996) and trigeminal nerve irritation (such as the burning sensation of capsicum pepper or cooling of menthol; Lawless & Stevens, 1984). For these reasons flavour is arguably multi-sensory, and it also shows influences from other senses such as olfaction (Small et al., 2004), and vision (DuBose, Cardello & Maller, 1980; see below, and Auvray & Spence, 2008 for a review). The integration of multiple senses when eating appears to be supported anatomically via the orbitalfrontal cortex (OFC) which is implicated as the site of integration for the components of flavour, and this serves as a "higher-order gustatory cortex" (Small et al., 2007, p. 136).

That flavour is comprised of more than just taste means flavour can of course be influenced by changes in modalities unrelated to taste. Hence the flavour of a food that is soft and heated would be different to one that is cold and crispy. Our interest here, however is to test how multisensory manipulations can effect taste evaluations themselves. We look at how participants rate taste qualities within flavoured food, if we alter modalities *other than* chemical tastants. Specifically we ask whether the taste quality of food becomes more sour, or sweet or bitter even if we modulate only texture.

Why consider the texture of food, and what predictions might we make? To preface our study we briefly review previous work that has used multisensory manipulations to evaluate changes in taste (as well as flavour and smell – since all three involve the chemical senses). We also look at what might be learned from studies of people with synaesthesia – an extreme type of multisensory integration – which could perhaps give insights into how evaluations of the taste components within food are made by the average person. In both cases we look especially at how multisensory integration sometimes involves hedonic qualities (i.e., the matching of two sensory qualities according to their pleasantness).

Cross-modal associations affecting smell, taste and flavour

A wide range of cross-modal associations relating to the perception of food have been reported. These studies tend to have one of two methods: either they manipulate one modality while measuring another (e.g., varying the colour of food while eliciting taste/flavour judgements from participants) or they ask participants to make intuitive matches across the senses (e.g., What shape seems to “best fits” this taste?). Studies such as these have revealed a variety of cross-modal influences on taste, flavour and smell. For example, both the smell and the taste/flavour of food is affected by its colour. Darker versions of the same cherry flavoured drink were rated as more intensely flavoured

(Philipsen, 1995; see also Chan & Kane-Martinelli, 1997). Colour can also affect evaluations of specific taste components within foods. Johnson and Clydesdale (1982) found participants rated darker red-coloured sucrose solutions as 2-10% sweeter (as a function of the amount of dye added) than a lighter solution, which in fact had a slightly stronger sucrose concentration. Smell too, can be modified by visual changes in food substances. When white wine was artificially coloured red, researchers found its smell was ascribed red wine qualities, leading to the conclusion that colour can act as a primer for smell (Morrot, Brochet and Dubourdieu, 2001).

Flavour evaluations can also be influenced by sound (see Spence & Shakar, 2010 for a review). For example, the sound of frying bacon leads participants to rate food as having more of a bacon flavour (Spence, Shankar & Blumenthal, 2010) and subjects eating crisps rated them as fresher and 'crispier' when listening to the sound of eating crisps played at higher volumes or with higher frequency sounds amplified. Similar results were found with the perceived 'fizziness' of carbonated drinks (Zampini & Spence, 2005) and even seemingly arbitrary sounds can exert influence over the perception of flavour. Participants rated beer as more enjoyable and flavoursome if accompanied by high versus low pitch sounds (Holt-Hansen, 1968, 1976, as cited in Spence & Shakar, 2010). High pitch sounds were also associated with the names of sour- or sweet-tasting foods (Crisinel & Spence, 2009;Crisinel & Spence, 2010a) while low pitch sounds were more associated with the names of foods that have either a bitter (Crisinel & Spence, 2009) or umami taste (Crisinel & Spence, 2010b). Similarly, Simner, Cuskley and Kirby (2010) found that participants making systematic associations between sounds and pure tastants preferred sweet tastes associated with smooth continuous phonetic sounds and sour tastes associated with staccato sounds.

Of particular interest to the current study are associations relating taste/flavour to touch and texture. Of course even before food enters the mouth there is an interaction between touch and vision, so judgements can be made regarding the shape of foods and of their surface texture (Verhagen & Engelen, 2006). Indeed, when interacting physically with food, the somatosensory system is important for multi-sensory integration (Verhagen & Engelen, 2006). The proprioceptive system is also an important source of information about the shape, size and texture of foods in the mouth, for example during oral exploration by the tongue (Cardello, 1996). But texture/touch can also influence flavour perception in more surprising ways. Bult, de Wijk and Hummel (2007) for example found interactions between viscosity and flavour, with less viscous milk receiving higher flavour ratings. Aside from texture, other touch related qualities (specifically, visuo-tactile qualities of shape) also influence judgements about foods, and even food names. Several recent studies, for example, have demonstrated shape-taste or shape-flavour associations. Ngo, Misra and Spence (2011) found that people associate more angular shapes with chocolate samples higher in cocoa content – which is a likely proxy for increasing bitterness. In a similar way, Spence and Gallace (2011) found angular shapes pairing with carbonated (versus still) water, and with other food products with a range of more complex flavours (e.g., cranberry juice but not brie). Finally, Deroy and Valentin (2011) produced analogous findings linking bitterness and carbonation to more angular shapes – this time in beers. These authors (Spence & Gallace, 2011; Ngo et al., 2011) also show that this type of angular (vs.

rounded) mapping can also manifests in preferred names for food products, given the particularly well-established linguistic link between angular shapes and certain types of words (e.g., nonwords containing plosives such as *kiki* and *takete*; Kohler 1926; Ramachandran & Hubbard, 1996). Together, these studies provide evidence for cross-modal interactions of texture, shape and flavour in everyday food consumption and even in the naming of foods.

In our study we manipulated the texture of food substances, but we also chose to consider the texture of the serving plate because studies have shown that eating receptacles, too, can influence food judgements. For example, the colour of a plate – but not its shape -- has been shown to exert an influence over how food is perceived: participants rated a strawberry mousse as more intense, sweet and likeable when it was presented on a white versus black plate. (Piqueras-Fiszman, Alcaide, Roura & Spence, 2012). Similarly, participants rated the taste of popcorn differently when eaten from coloured bowls as opposed to white ones: sweet popcorn was perceived as saltier when eaten out of a coloured (vs. white) bowl, and vice versa for salty popcorn (Harrar, Piqueras-Fiszman & Spence, 2011). Even the choice of cutlery can influence the flavour and enjoyment of foods if these cutlery carry their own tastes (e.g., zinc- and copper-coated spoons were rated as less pleasant-tasting, and in turn they enhanced the perception of certain hedonically negative tastes such as bitterness; Laughlin, Conreen, Witchel & Miodownik 2011; Piqueras-Fiszman, Laughlin, Miodownik, Spence, 2012). These studies show that the qualities of even cutlery and plates can influence taste and flavour. Since our focus in the current paper is on texture, we will manipulate the texture of plates to see whether this influences the perception of the taste components within flavoured foods.

Finally we point out that cross-modal associations may form on the basis of a hedonic association, i.e. associations may form because sensations regarded as equally pleasant or unpleasant can be grouped together. Evidence suggests this is indeed the case, at least in some areas of flavour, taste and smell. For example, Simner et al. (2010) asked participants to free associate sounds to tastants deposited on their tongues. Simner and colleagues found that tastes known to be 'pleasant' (e.g. sweet) tended to map to 'pleasant' sounds, such as smooth continuous vowel sounds, while sounds rated as unpleasant, such as high pitched staccato sounds, were associated with unpleasant tastes such as bitterness. In another study, the presentation of odours rated as pleasant (e.g. lemon) led participants to rate fabrics as softer than when in the presence of unpleasant odours (the scent of animals; Demattè, Sanabria & Spence, 2006). Finally, we noted above that spoons covered with metals that had negatively-rated tastes tended to enhance the perception of hedonically negative tastes such as bitterness (Laughlin et al., 2011; Piqueras-Fiszman et al. (2012). In the current study we will consider whether texture-taste mappings might arise from hedonic considerations (e.g., roughness linked to negative tastes such as sour/bitter, and smoothness linked to positive tastes such as sweet). Before this, we briefly review texture interactions with taste, flavour and smell in individuals with synaesthesia.

The interaction of Taste/flavour/smell and Touch in Synaesthesia

Synaesthesia is a familial neurological condition affecting at least 4.4% of the population (Simner et al., 2006). It results in unusual but benign perceptual experiences in which stimulation within one sensory modality evokes an automatic involuntary experience in another (e.g. for reviews see Simner & Hubbard, 2013; Baron-Cohen & Harrison, 1997). For example, synaesthetes might experience sensations of colour when they hear sound (e.g., Ward, Huckstep, Tsakanikos, 2006). In scientific parlance, the trigger for synaesthesia (here for example, sound) is termed the 'inducer' and the resultant synaesthetic perception (here, colour) is termed the 'concurrent' (Grossenbacher & Lovelace, 2001). Synaesthesia is of interest to our current aims because research suggests that cross-modal associations in synaesthetes may share the same or similar underlying mechanisms as those found intuitively in the general population (see Simner, 2013 for review). For example, sound-colour synaesthetes experience lighter synaesthetic colours when listening to higher pitch sound, and non-synaesthetes, too, tend to pair lighter colours with higher pitch when matching colours to sounds intuitively (Ward et al., 2006). Both synaesthetes and non-synaesthetes therefore make associations across the senses in a non-random way, and both follow certain underlying rules, often shared across groups (see also Simner & Ludwig, 2012; Ward et al., 2006). We therefore suggest that research into synaesthesia is not only interesting of itself, but it may also elucidate normal brain functioning and cognition (see also Cohen Kadosh & Henik, 2007). We consider this below in making our predictions about how texture and taste might correspond in the general population.

As in the general population, a number of synaesthetic associations may derive from hedonic matching. Consider for example synaesthesias involving the chemical senses – our current interest here. One recent study (Russell, Stevenson & Rich, in press) has shown that the nature of the synaesthetic experience is derived via the hedonic quality of the inducer. These researchers looked at synaesthetes experiencing coloured shapes triggered by odours; they showed that odour stimuli rated as hedonically similar were more likely to produce similar colours/shapes in the synaesthesia (Russell et al., in press). In another variant of synaesthesia, hedonic qualities might also appear to drive the pairing of inducer and concurrent. Cytowic (1995) described the case of synaesthete MW, whose synaesthesia manifests as tactile sensations of shapes against his hands triggered by the taste of food in his mouth. Of particular relevance to the current research, it was found that sour foods add unpleasant tactile qualities of roughness, specifically 'points' or 'prickles', to the synaesthetic touch (Cytowic, 1993; Cytowic & Wood, 1982). Again, these associations may be mediated by hedonic evaluations in that unpleasant tastes tend to pair with unpleasant textures (e.g., sourness with prickles/roughness) and descriptions within that case-report do appear to suggest this: "[MW's] synesthesiae were usually pleasurable and sensuous. Rarely, he felt … a "pricking' in his fingertips, "like laying my hand on a bed of nails. Mostly this happens with really sour foods." (Cytowic, 1993; p. 66).

Finally, one other case-report of synaesthesia describes what might be considered a type of hedonic matching in taste-touch interactions. Luria (1987) describes the famous case of synaesthete S. who experienced multiple synaesthesias including interactions of taste and texture. Again, at least some reports suggest a link between hedonically negative tastes and rough, prickly textures. Hence Synaesthete S. describes a tone he heard played at 2,000 cycles per second as looking like a “fireworks tinged with a pink-red hue. The strip of color feels rough and unpleasant, and it has an ugly taste – rather like a briny pickle” (Luria, 1987; p. 23). Again this mapping involves interactions between what might be argued to be a hedonically negative texture and a hedonically negative flavour. There may be too few examples within this case report to know whether this is found systematically in synaesthesias across the chemical senses, so instead we take a slightly different approach here. We begin with the assumption that certain types of associations found by synaesthetes are often mirrored in the general population (see Simner, 2013 for an extensive review) and on this basis, we explore whether we can find evidence of hedonic mapping between texture and taste within the experiences of the general population.

Overview of Present Study

In this study we tested a group of non-synaesthete adults from the general population on a task involving the detection of the taste components within flavour. We ask two specific questions: do average people experience implicit cross-sensory associations between taste/flavour and texture, and is there any evidence of hedonic mapping? Following the evidence reviewed above from both synaesthetes and non-synaesthetes, we hypothesise that pairing a hedonically negative tactile stimulus (roughness) with a given foodstuff might cause an enhancement of hedonically negative tastes within that food (sourness or bitterness, but not sweetness).

In our study participants were asked to rate the taste qualities of a flavoured food substance presented for consumption. The food was presented either as a rough versus smooth solid, or it was presented in a gelatinous form, but on a serving-plate that was either rough versus smooth. Our food substances had qualities of sourness, bitterness and sweetness and we predict that these might be rated as tasting more hedonically negative (i.e., more sour/ bitter or less sweet) when presented with a rough texture – either textured on the food itself (Experiment 1) or textured on the serving-plate (Experiment 2).

Experiment 1

Participants

Thirty-eight participants (Mean age = 22.3, SD = 4.1; 26 females) took part in this study. In verbal reports, all confirmed they had no food allergies, were non-smoking and knew of no other factor affecting their ability to taste (see Mann, 2002). Participants were also provided with a detailed information sheet about synaesthesia providing a number of different examples, including examples of synaesthesias involving the senses of taste and touch. After reading this information, participants confirmed they did not have the condition (and any subject suggesting otherwise was not permitted to enter our sample). All methods were approved by the University of Edinburgh Psychology Ethics Committee and participants were recruited on a voluntary basis from the University of Edinburgh community.

Materials and Procedure

Participants consumed a food sample, and then rated its qualities of sweet, sour and bitter using three separate 5-point Likert scales (0 = quality not present, 4 = quality intensely present). The food sample was a solid 2.5g sucrose mixture, consisting of sugar, glucose syrup and vegetable oil, combined with citric acid (sold commercially as fondant icing sugar mixed in our lab with concentrated lemon juice). This foodstuff was selected because previous (unpublished) studies in our lab have shown it to have a complex flavour of sweet, bitter and sour. The foodstuff formed a thick and smooth paste which was split in half to form a common base for both our experimental conditions (see below). Granulated sugar was then added to this base in the ratio of 1:3, and this sugar was either finely ground or in its raw coarse state to create the smooth- and rough-textured conditions respectively. Preparations were then formed into spheres and were finally rolled in a small amount of the corresponding sugar type (finely ground or granulated), giving a total weight of each stimulus of 2.5g and either a rough or smooth surface, as shown in Figure 1. Stimuli were left to dry for 48 hours to form solid hard spheres (rough or smooth). Half the participants were randomly allocated to receive their food sample in the rough condition and half the smooth condition, with all foodstuffs otherwise identical in mass and composition.

Figure 1. Experiment 1 stimuli: Smooth- and rough-textured foodstuff samples.

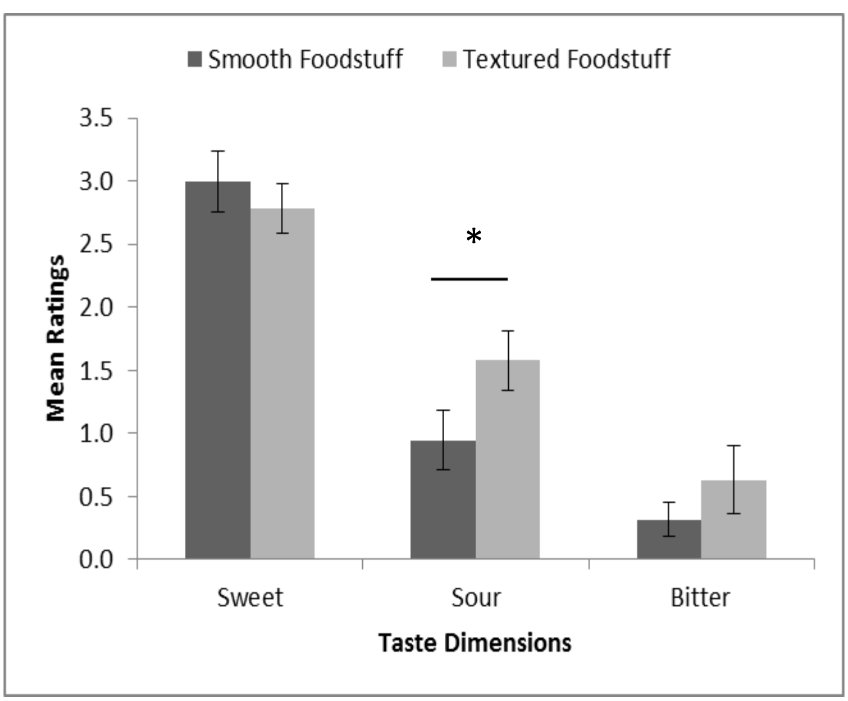
Verbal and written instructions explained that participants should taste the sample and think about its taste qualities and record their impressions promptly (i.e., rather than attempting to determine the nature of the product or answering based on prior belief or expectation; see Morrot et al., 2001; Levitan et al., 2008). They were reminded that their rating of one quality (e.g. sour) does not affect their rating of another (e.g. sweet) – i.e. each quality is to be rated separately of the others. Participants recorded their answers on a form where they also provided demographic information. Cutlery was not permitted (to avoid any additional bias, see Piqueras-Fiszman, Laughlin, Miodownik & Spence, 2012) so food was handled with the fingers. Participants were tested individually in a quiet environment, and the test lasted approximately 10 minutes per subject.

Results

Using PASW Statistics 17.0, mean taste dimensions were compared separately (because they constituted individual data 'families' and because we had no *a priori* assumptions about how each taste component might interact if compared directly). Two-tailed Mann-Whitney U tests were used as data did not meet assumptions of normality or homogeneity.

Ratings of the sweet, sour and bitter taste qualities of the smooth and rough stimuli are shown in Figure 2. There was a statistically significant difference between smooth and rough stimuli within the ratings for sour ($U_{Sour} = 113.50$, $Z = -2.04$, $p = 0.02$, $r = -0.33$) but no significant differences between rough and smooth within the ratings of sweet or bitter ($U_{Sweet} = 153.00$, $Z = -0.84$, $p = 0.20$, $r = -0.14$; $U_{Bitter} = 165.50$, $Z = -0.55$, $p = 0.58$, $r = -0.09$). In other words, foodstuff presented in a rough-textured sphere was as rated significantly more sour than foodstuff presented in a smooth sphere.

Figure 2. Mean ratings of foodstuff taste dimensions as a function of foodstuff texture, error bars indicate SEM. Note: *p < 0.05



Foodstuff served as rough-textured was rated as significantly more sour than when served as smooth-textured. The direction of the effect is as predicted by our hypothesis: rough texture is arguably hedonically negative and this texture enhanced the hedonically negative taste of sourness. However, it did not enhance bitterness (another hedonically negative taste) although there was a numerical trend in this direction. We point out that our finding is perhaps all the more surprising when we consider how flavour perception is known to be influenced by expectation (e.g. Morrot et al., 2001; Levitan et al., 2008). In the rough condition, there were visible sugar granules on the outside of the rough foodstuff, which might have promoted higher judgements of sweetness. This did not happen and our findings were instead in line with our predictions: the rough-textured foodstuff was associated with sour tastes, and the reasons for this will be considered in the general discussion.

Experiment 2

Participants

Our participants were 38 adults recruited from the same population as Experiment 1 (mean age = 22.1 years; SD=4.2; 25 females). Participants were given the same screening questions as in the previous study and again, all those included reported being non-smoking non-synaesthetes. Of these, 32 also took part in Experiment 1. For participants who took part in both studies, a break occurred between testing sessions of at least 15 minutes and we fully counterbalanced their four conditions across both experiments (i.e., smooth sphere, rough sphere, smooth serving-plate, rough serving-plate).

Materials and Design

As in Experiment 1, participants consumed a food sample, and then rated its qualities of sweet, sour and bitter using separate, 5-point Likert scales (0 = quality not present, 4 = quality intensely present). All elements of this study were identical to Experiment 1 except the following. In the current study, the foodstuff was a 5ml serving of a glucose-fructose gel with lemon citric acid and a gelling agent (sold commercially as the product lemon curd). This mixture was chosen because, again, previous studies in our lab had shown it has a relatively complex flavour including the taste qualities of sweet, sour and bitter. All participants received their foodstuff on a flat square plastic serving-plate. For half of the participants the serving-plate was rough in texture and for the other half it was smooth in texture (see Figure 3). Both serving-plates were otherwise perceptually matched, on colour, size, shape and material (i.e., except for our manipulation of texture). All other elements of our design were as described in Experiment 1.

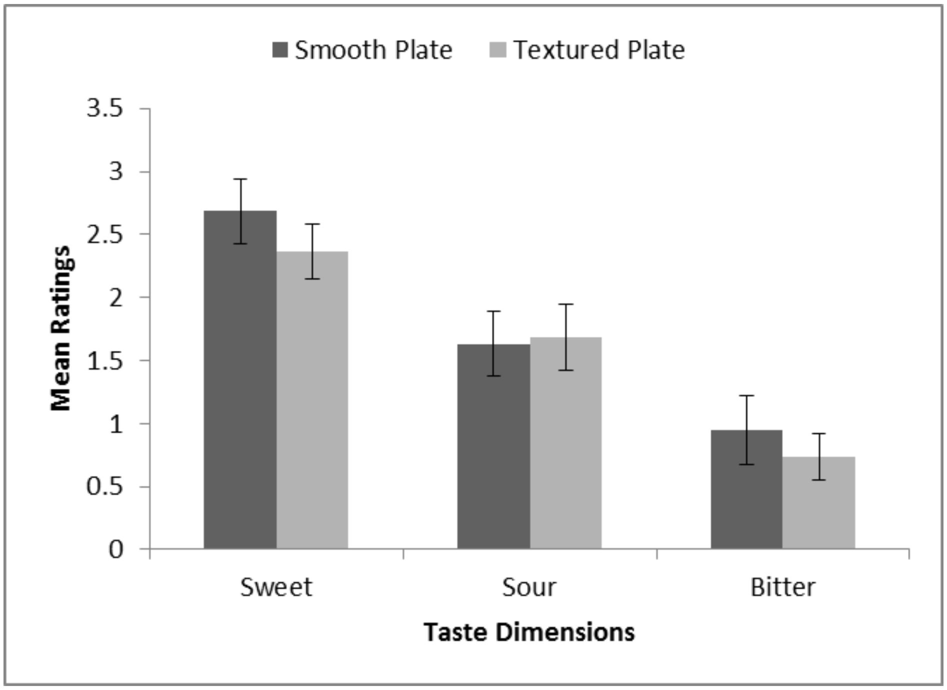
Figure 3. Experiment 2 stimuli: Smooth and textured plates with foodstuff sample.

Results

As described in Experiment 1, we again used PASW Statistics 17.0 to compare the smooth versus rough condition within each family of data, using separate two-tailed Mann-Whitney U tests because data did not meet assumptions of normality or homogeneity.

Ratings of the sweet, sour and bitter qualities taste qualities of the smooth and rough stimuli are shown in Figure 4. Our Mann-Whitney U tests revealed no statistically significant differences as a function of plate texture in any of our measures: $U_{Sweet} = 151.00$, $Z = -0.89$, $p = 0.43$, effect size $(r) = -0.14$; $U_{Sour} = 175.00$, $Z = -0.17$, $p = 0.89$, $r = -0.03$; $U_{Bitter} = 175.00$, $Z = -0.16$, $p = 0.87$, $r = -0.03$.

Figure 4. Mean ratings of foodstuff taste dimensions as a function of plate texture, error bars indicate standard error of the mean (SEM).



Discussion

None of the comparisons within data reached statistical significance suggesting that the taste components of flavoured food were not influenced by the texture of the serving surface. This could possibly be because the texture difference between conditions was too subtle, and we address this – and our other findings -- in more detail in the general discussion.

General Discussion

In our studies we asked whether the perception of taste components within flavour can be altered by cross-sensory manipulations in texture. In a general population of average (non-synaesthetic) adults, we asked participants in Experiment 1 to rate the sourness, sweetness and bitterness of a solid food substance which we manipulated in texture. We found that a rough-textured foodstuff was rated as more sour-tasting than an otherwise identical smooth-textured foodstuff. We further examined whether this influence of texture extended to other extraneous surfaces: in Experiment 2 we asked participants to evaluate the sweetness, sourness and bitterness of a gelatinous foodstuff placed on a serving-plate that was either rough or smooth. We found no effect in this second study meaning that the texture of the serving plate did not influence taste ratings within the flavoured food. However, we point out that the difference in texture across serving-plates in Experiment 2 was relatively minor (see Figure 3) so we are planning subsequent studies in our lab to now exaggerate those differences. It is possible that taste differences might yet emerge if our relatively subtle textural differences in this study were exaggerated.

Our findings in Experiment 1 amount to demonstrating a type of ‘multi-sensory illusion’, which provides false information about taste qualities based on visuo-tactile information fed to senses other than chemically-mediated gustation. Properly speaking, gustation refers to the detection of tastants molecules by flavour receptor cells (Chandrashekar et al., 2006). Although flavour combines multi-sensory elements of taste, texture, temperature, and so on (for review see Auvray & Spence, 2008) our participants were rating taste qualities in particular, within those flavoured foods. We tentatively suggest that the direction of our multi-sensory findings may arise, in part, from hedonic matching (e.g. Demattè et al., 2006). Our review of multisensory flavour perception in synaesthetic and non-synaesthetic populations suggested that some type of hedonic evaluation may mediate associations involving the chemical senses. We tentatively suggest that our results also appear to fall in this direction.

We take care to point out however that we have not tested hedonics specifically (see for example, Russell et al., in press), but our data support the direction of a hedonic account. For this we have assumed that sourness is a hedonically negative taste, although we also point out that we found no effects within bitterness –another hedonically negative taste. We note here there is some evidence to suggest that sourness and bitterness are often confused when describing foods (O'Mahony, Goldenberg, Stedmon & Alford, 1979) which might be relevant in the present context. In both sourness and bitterness we found numerically greater ratings from rougher foodstuffs, and it may be that some amount of influence from bitterness was carried into the ratings of sour, or vice versa. Nonetheless, given that our *significant* findings were limited to sourness, we interpret our data in terms of hedonics only with caution: further study is required to rule out other interpretations. Future work might also assess whether the same types of effect might be found when pure tastants are presented as opposed to complex flavours. Here we presented sweet, sour and bitter tastes together within a single complex foodstuff, but would a stimulus that was purely sweet (or sour, or bitter) also increase in sourness if presented within a rough texture?

An alternative proposal to our hedonic account might relate to learning. Previous studies have suggested that at least some cross-sensory associations can be explained by learned cues in the environment. For example, in free-choice tactile-visual mappings, smoother texture pairs with high visual luminance, perhaps because smoother surfaces reflect greater light in real-world environments (Simner & Ludwig, 2012; Ward, Banissy & Jonas, 2008). However, this learning account might be questioned here: naturally-occuring sour foods are not necessarily rougher, and naturally-occurring foods do not move from rough to smooth as they ripen to sweetness – at least not to our knowledge. However, it is yet possible that associations can be learned from man-made products, which – even if they do not naturally occur – are nonetheless available within our food environment (e.g., one widely-selling food product in the UK is roughly coated fruit sweets with a notably sour tang aftertaste). In the absence of a full review of foodstuff, any learning account cannot be ruled out.

The direction of our data might also speak to neuropsychological cases where flavour-shape correspondences become consciously experienced in unusual ways. Importantly, we reviewed research suggesting that synaesthetic perceptions may be “non-random” in that they can form rule-like systems which reflect the type of multimodal associations found in all people (Simner et al., 2005; Cohen Kadosh & Henik, 2007; Ward et al., 2006). In other words, despite differences across synaesthetes and non-synaesthetes in the phenomenological nature of flavour-shape associations (which only synaesthetes experience consciously) both populations may follow similar cross-sensory ‘rules’. Given our tentative hedonic account in the current study, and the same direction of results wthin studies of synaesthetes, our research might contribute to the emerging view that cross-modal associations in non-synaesthetes share underlying mechanisms with synaesthesia (Simner et al., 2005; Cohen Kadosh & Henik, 2007; Ward et al., 2006). We look to future research to test this more directly using a wider range of hedonically varying taste/texture stimuli.

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